New Model Variable Frequency Transformer (NMVFT) – A Technology for V/f Control of Induction Motors

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Abstract— **Variable frequency transformer (VFT) is used as a controllable bidirectional transmission device that can transfer power between asynchronous networks and functionally is similar to back-to-back HVDC. This paper describes the basic concept of a New Model Variable Frequency Transformer (NMVFT). NMVFT is a new technology which is used for v/f control of induction motors. A digital simulation model of NMVFT and its control system are developed using MATLAB. The out power thus generated in v/f mode has been practically verified for the speed control of a three-phase induction motor. Thus constant speed-torque characteristics were achieved.**

***Index Terms*—Variable frequency transformer (VFT), Asynchronous, New Model Variable Frequency Transformer (NMVFT), V/f control, MATLAB.**

I. Introduction

Variable frequency transformer (VFT) is a controllable bidirectional transmission device that can transfer power between asynchronous networks. The construction of VFT is similar to conventional asynchronous machines, where the two separate electrical networks are connected to the stator and rotor respectively. One power system is connected with the rotor side of the VFT via the electrical brush rings and step-up transformers. And another power system is connected with the stator side of the VFT directly via a step-up transformer. Electrical power is exchanged between the two networks by magnetic coupling through the air gap of the VFT. A motor and drive system are used to adjust the rotational position of the rotor relative to the stator, thereby controlling the magnitude and direction of the power flowing through the VFT [1, 2].

Both the winding currents of the stator and rotor induce a rotary magnetic field F_{stator} and F_{rotor} respectively. In the steady state, the two rotary magnetic fields are rotating with the same angular speed i.e. F_{stator} is standstill to F_{rotor}. The composite magnetic fields F_{stator_rotor} will rotate with a speed of $\omega_{system\text{-}stator}$, cutting the stator coils with the same speed, and cutting the rotor coils with a speed of ω_{system_rotor}. And the angle frequency of the resulting inductive potential at stator and rotor windings is synchronous with their currents respectively. A stable power exchange between the two asynchronous systems is possible. The transferred power and its direction are controlled by the torque applied to the rotor, which is supplied by the dc drive motor. If torque is applied in one direction, then power flows from the stator winding to the rotor winding. If torque is applied in the opposite direction, then power flows from the rotor winding to the stator winding. If no torque is applied, then no power flows through the rotary transformer [3, 4].

The world's first VFT, which was manufactured by GE, installed and commissioned in Hydro-Quebec's Langlois substation, where it will be used to exchange power up to 100 MW between the asynchronous power grids of Quebec (Canada) and New York (USA). Figure 1 shows a simplified one-line diagram of the Langlois VFT, which is comprised of the following: a rotary transformer for power exchange, a drive motor to control the movement of the rotor and to transfer power, a collector to connect the rotor windings with the outside system via electric brushes [5 - 7].

Figure 1. Photograph of Langlois 100 MW VFT

II. NMVFT Model And System Description

A. NMVFT Model

In the model, NMVFT is a three phase singly fed slip ring type induction machine. The stator winding is energized with three phase ac source and the rotor winding is kept open. The rotor is coupled to a controllable constant speed drive i.e. dc shunt motor via mechanical coupler and

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scope is connected to measure the magnitude of voltage and frequency of voltage across the rotor winding. Figure 2 shows the circuit diagram of NMVFT.

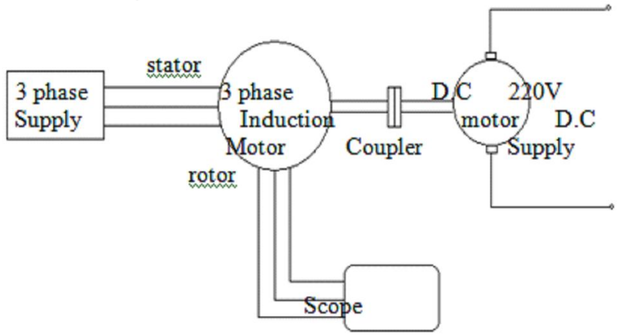


Figure 2. NMVFT circuit diagram

B. NMVFT Operation

The three phase ac supply is applied to the stator winding of the three phase four poles singly fed slip ring type induction machine. The rotor is coupled with the dc shunt motor through a mechanical coupler. When the 220V dc supply is applied to the dc shunt motor the NMVFT comes in operation. The induced emf 'E_r' in the rotor circuit is given by

$$E_r = sV \qquad (1)$$

where,

V = Supply voltage per phase,

s = Slip of Induction Motor and

E_r = Emf induced in the rotor circuit per phase

And the frequency of the induced voltage in the rotor circuit is given by

$$f_r = sf \qquad (2)$$

where,

f = Supply frequency,

s = Slip of Induction Motor and

f_r = frequency of the induced voltage in the rotor circuit

The operation of NMVFT includes the following:

i) If the rotational speed of dc shunt motor is zero then the value of slip is equal to one as a result the emf induced across the rotor winding is the rated rotor terminal voltage and the frequency of voltage is the rated frequency.

ii) If the dc shunt motor rotates in

a)The direction of the rotating air gap flux then the relative motion between them decreases results in decrease in slip as a result the emf induced across the rotor winding as well as its frequency decreases. When the speed of rotation of dc shunt motor is equal to synchronous speed then the slip becomes zero as a result the emf induced a) across the rotor winding as well as its frequency becomes zero.

b)The direction opposite to the rotating air gap flux then the relative motion between them increases results in increase in slip as a result the emf induced across the rotor winding as well as its frequency increases. When the speed of rotation of dc shunt motor is equal to synchronous speed then the slip becomes double as a result the emf induced across the rotor winding as well as its frequency becomes double the rated value.

Thus a constant V/f characteristics is achieved. This operation of NMVFT is verified digitally by MATLAB Simulation and practically.

III. Digital Simulation Of VFT

A. MATLAB Simulation

In the view of MATLAB simulink, NMVFT is a type of machine which can be simulated with the asynchronous machine SI units. The asynchronous machine SI units having a three-phase excitation system on stator side. The constant speed achieved from dc shunt motor is simulated by using a constant block. And then we could use this simulated model, as shown as Figure 3, to solve electric system of NMVFT.

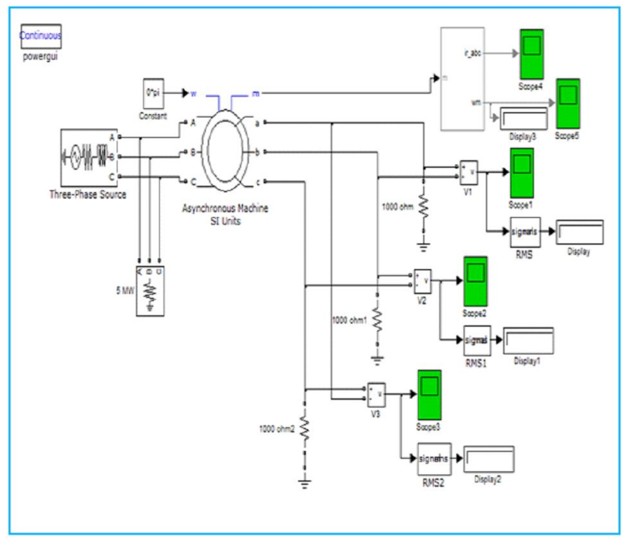
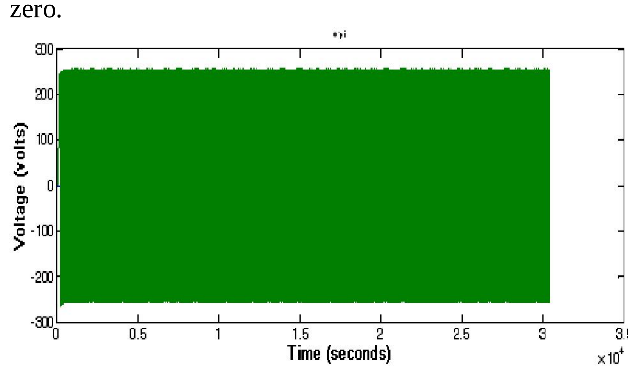


Figure 3. MATLAB Simulation diagram of NMVFT

B. Simulation Figures and Results

When the rotational speed of dc shunt motor is zero.



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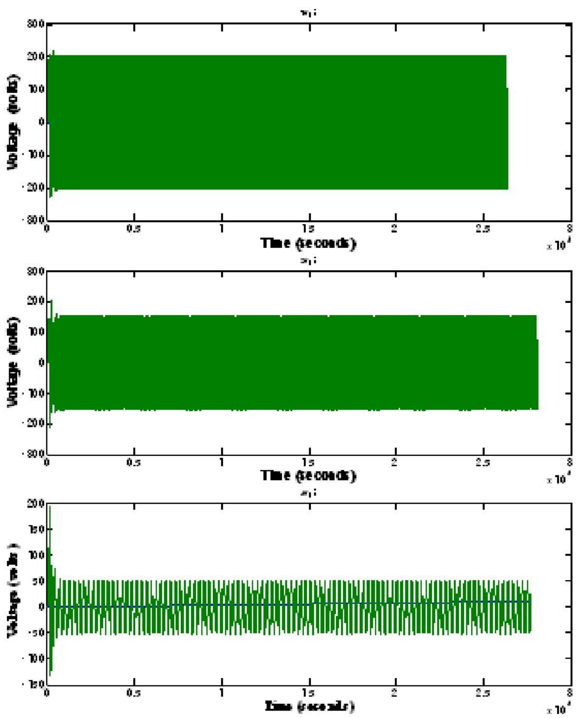
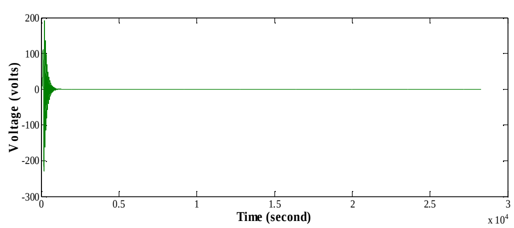
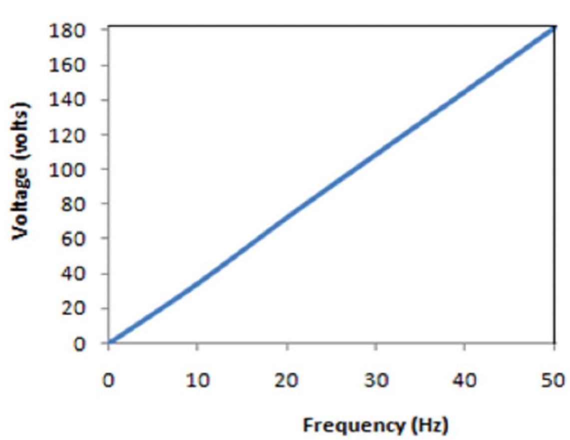
a) The direction of rotation of rotor is same as that of the air gap field:-



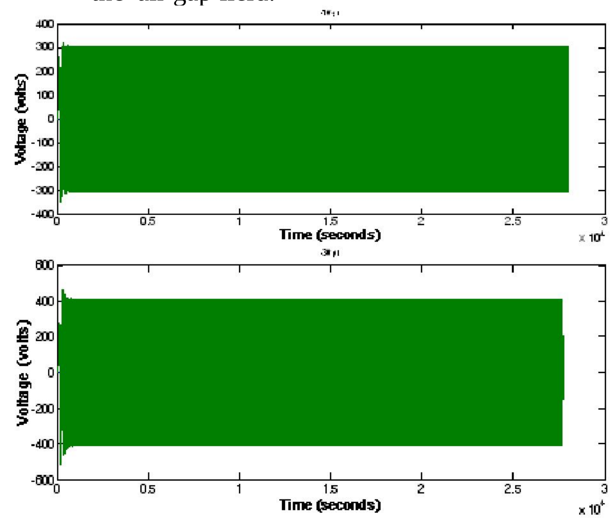
When the rotational speed of dc shunt motor is equal to the synchronous speed i.e. relative speed is zero.



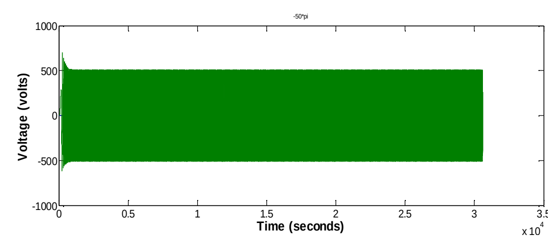
In this way we can control output voltage from zero volts to rated voltage and frequency from zero Hertz to rated frequency i.e. 50 Hz in India. The emf induced across the rotor winding versus its frequency graph achieved is shown as:



b) The direction of rotation of rotor is opposite to the air gap field:-



When the rotational speed of dc shunt motor is equal to the synchronous speed i.e. relative speed is double of synchronous speed.



In this way we can control output voltage from rated voltage to twice of rated voltage and frequency from rated frequency to twice the rated frequency i.e. 50 –100 Hz in India. The emf induced across the rotor winding versus its frequency graph achieved is shown as:

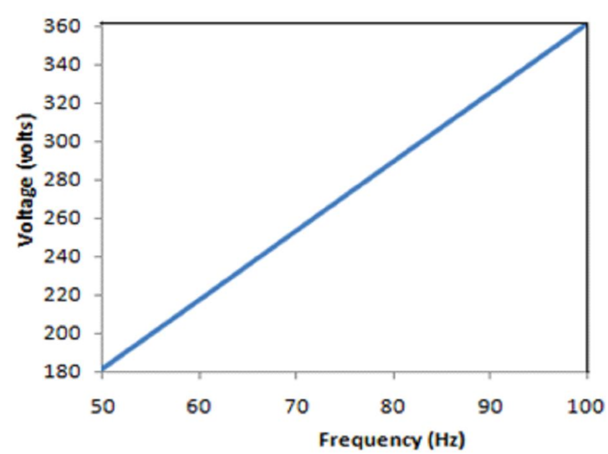


Figure 4. MATLAB Simulation results showing variation of rotor circuit voltages with time and voltage versus frequency graphs.

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IV. PRACTICAL ANALYSIS

S.No	Equipment	Specification
1.	D.C Shunt Motor	0.75HP, 3.8A, 220V,1500rpm
2.	Induction Motor	420V, 4.4A, Y-Y, cosØ=0.83,1430rpm Rotor : 210V, 7.3A
3.	Auto transformer	3 phase,22.799KVA, 0-470V,28A
4.	Rheostat	0-350Ω,3.0A
5.	Voltmeter	0-250V, M.I
6.	Tachometer	0-3000rpm
7.	Oscilloscope	Tectronix

Figure 5. Mechanical and electrical parameters used during experiment.

While performing the experiment the rotor of dc shunt motor is mechanically coupled to the rotor of the induction motor. The three phase ac supply is given to the stator winding of three phase four poles slip ring type induction motor through an auto transformer. The rotor windings are kept open circuited and voltmeter is connected across the rotor winding. The 220V dc is applied to the dc shunt motor through a rheostat. A tachometer is used to measure the speed of the dc shunt motor. With the help of auto transformer the input voltage of induction motor is maintained constant and through rheostat the voltage of the dc shunt motor is varied which varies the current in shunt winding and as a result the flux of dc shunt winding varies, resulting in variation of speed of dc shunt motor. Since the rotor of dc shunt motor is mechanically coupled with the rotor of induction motor, thus the speed of the induction motor varies accordingly. The voltage induced across the rotor winding and its frequency is given in the table:

a) The direction of rotation of rotor is same as that of the air gap field:-

TABLE I.
VARIATION OF ROTOR VOLTAGE AND ITS FREQUENCY WITH SPEED

S.No	Speed of D.C Shunt Motor (rpm)	Voltage across rotor winding (volts)	Frequency of rotor voltage (Hz)
1.	0	180	50.0
2.	201	156	43.3
3.	398	132	36.8
4.	605	107	30.0
5.	802	84	23.3
6.	998	61	16.8
7.	1203	36	10.0
8.	1498	0	0.0

Figure 6 showing the variation of rotor voltage with its frequency of table I.

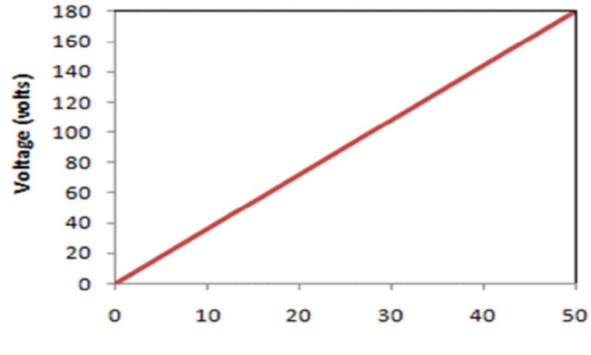

Figure 6. Voltage versus Frequency curve (table I)

b) The direction of rotation of rotor is opposite to the air gap field:-

TABLE II.
VARIATION OF ROTOR VOLTAGE AND ITS FREQUENCY WITH SPEED

S.No	Speed of D.C Shunt Motor (rpm)	Line Voltage across rotor (volts)	Frequency of rotor voltage (Hz)
1.	0	180	50
2.	198	204	56.6
3.	260	210	58.5
4.	402	227	63.0
5.	703	265	73.5
6.	850	282	78.2
7.	1025	303	84.2
8.	1254	332	92.0
9.	1492	360	99.7

Figure 7 shows the variation of rotor voltage with its frequency of table II.

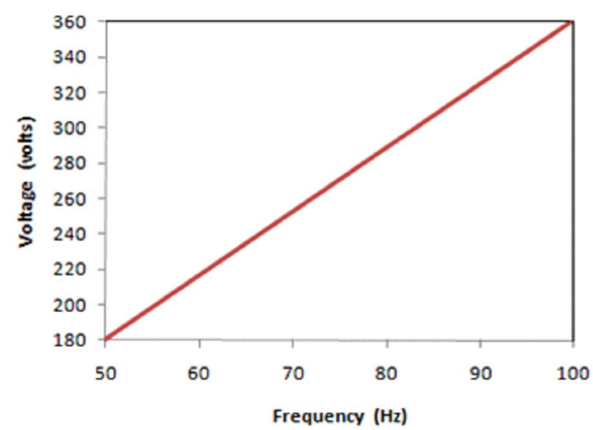

Figure 7. Voltage versus Frequency curve (table II)

V. INDUCTION MOTOR V/F CONTROL

The output power of the NMVFT is applied to three phase induction motor of 1HP, 420V, 2A, 50Hz, 1430rpm. A linear torque-speed characteristics is achieved. The torque-speed characteristics for different magnitude of voltage and different frequency of voltage i.e. 50Hz, 40Hz and 30Hz, with and without boost up voltage, are shown as:

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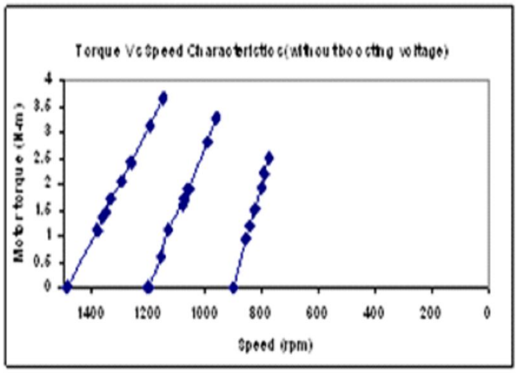

Figure 8. Torque versus Speed characteristics (without boost-up voltage)

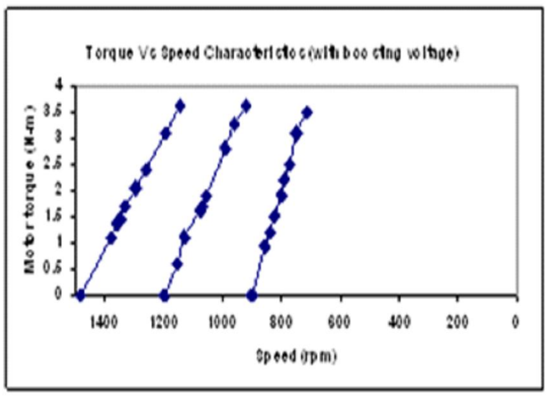

Figure 9. Torque versus Speed characteristics (with boost-up voltage)

Figure 10. Front view of NMVFT setup

Figure 11. D.C Shunt motor mechanically coupled with Induction motor

Conclusions

Using NMVFT we can vary voltage from zero volts to twice the rated voltage and frequency from zero hertz to twice the rated frequency. Thus a constant V/f is achieved by NMVFT and is harmonics free. This is a new alternative for v/f control of Induction Motor. It eliminates the use of conventional v/f power supply using a MOSFET or IGBT based inverter. Therefore the reliability of the system is high and the proposed system can be used at MW level of power. MATLAB based simulation is done for the overall performance of the NMVFT system. Moreover, a satisfactory performance of a three-phase induction motor is also obtained, when energized form the NMVFT supply. It showed almost linear torque-speed characteristics.

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